ONR MECHANICS & ENERGY CONVERSION DIVISION

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CONTRACT TITLE: CLEAN, AGILE PROCESSING TECHNOLOGY

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PROGRAM OBJECTIVES & GOALS

The "Clean, Agile Manufacturing of Propellants, Explosives, and Pyrotechnics" (CAMPEP) program managed by ONR and funded by the Strategic Environmental Research and Development Program (SERDP) has an overall goal of enabling a 90% reduction in pollution and scrap from the Nations PEP life cycle. Lockheed Martin Missiles & Space (LMMS) is contributing to the portion of CAMPEP dealing with PEP processes in an effort to eliminate or reduce scrap and to facilitate recycle/recovery of PEP materials. We are focusing on selected PEP processes to understand how the physical/chemical behavior of the propellant or explosive in the process affects the scrap and pollution generated by the process. Gaining this understanding will allow us to improve and control the selected processes to demonstrate pollution reduction. The tools developed for achieving this aim will then be proven and transferable to other PEP processes, furthering the overall SERDP goal.

This Program is closely aligned with related programs at other sites involved in the SERDP-sponsored research on the processing science of energetic materials. These groups include the Naval Surface Weapons Center-Indian Head Division (NSWC), Stevens Institute of Technology (SIT), Los Alamos National Laboratory (LANL), Sandia National Laboratory, the California Institute of Technology (CIT), the Massachusetts Institute of Technology (MIT), and the Naval Air Warfare Center (NAWC), China Lake.

RESULTS

The LMMS Program began on 7 June, 1995 with full funding. In April 1995, a meeting at the Yorktown, VA detachment of the NSWC was attended to plan research activities relevant to the JSOW and TOMAHAWK programs (BLU-97 munitions) and other DOD PEP processing programs. As a result of this meeting it was decided that a major endeavor at LMMS should be the study of PEP-type suspension flows that occur in injection loading of BLU-97 and similar processes. To facilitate this endeavor, a mockup of the NSWC injection loader has been designed for use in the LMMS magnetic resonance imaging (MRI) system. This one-half-scale mockup will allow us to obtain images of the concentration and velocity histories of highly filled suspensions as they are processed through the injection loader. For the first time we will be able to obtain a direct view of the phenomena (particle migration and matting, etc.) that are responsible for uncontrolled variations in munition quality (performance).

Our mockup injection loader consists of an epoxy-fiber overwrapped plastic tube for the main pressure vessel and contraction throat. Fiber overwrapping is necessary to fortify the tube

against the high internal pressures (~1000 psi) anticipated as a result of the scaled-down injector throat. All other components of the mockup (e.g. injection ram) are also designed to be made from non-metallic parts to allow magnetic resonance images to be obtained as the suspension is processed. Mockup fabrication was completed. The injection loader was tested outside the LMMS MRI magnet before proceeding with MRI studies. We are refined our MRI techniques to improve our ability to map velocities and concentrations in the mockup. One aspect of this effort is to improve the signal to noise and accuracy of velocity measurements by MRI over what was achieved in our earlier work. The MRI gradient and rf sequences are being analyzed to determine if more information can be extracted from the images to reduce inherent errors in the measurements.

In another effort, a review paper on capillary flows of concentrated suspension has been started at LMMS in conjunction with NAWC. This technical paper, to be submitted to a refereed technical journal, is aimed at summarizing the potential difficulties in using capillary rheometry to measure viscosity and apparent wall slip of propellants, explosives, and pyrotechnics (PEP).

Finally, magnetic resonance images of particle concentration distributions resulting from strain of a highly filled suspension in a cone-and-plate rheometer cell were acquired. These images were analyzed in conjunction with a theoretical treatment of particle migration worked out by Dr. David Leighton of Notre Dame University. Reasonable agreement was found between the experimental (MRI) data and theoretical predictions. This result is significant since it identifies modifications needed to the basic particle migration theory originally formulated by Philips, et al. to account for "curvature" effects in non-rectilinear flows. Real processing situations contain many types of flows which may not be adequately covered by the original theory. Our results represent a significant start on addressing this missing portion of the process modeling capability. A paper describing our cone-and-plate experiments is in preparation for submission to a technical journal.

FUTURE RESEARCH PLANS

Once the injection loader mockup is thoroughly tested, imaging studies of suspension flow will start. Variables which can be adjusted in these studies are flow rate, particle loading and particle size distribution, suspension viscosity, and injection contraction ratio. The effects of particle size on particle migration can be examined if migration if observed. Results will be compared to the expectations of particle migration theory to determine how to best model this process. The phenomena responsible for the high initial pressure required to move material in the NSWC injection loader can be investigated. Processing conditions which lead to particle matting, where particles and the suspending fluid segregate at the flow contraction, will be determined. Our results are expected to be useful to identify conditions under which concentration non-uniformity would result and the underlying mechanisms for the undesirable non-uniformity. From a practical standpoint, the results will help pinpoint either modifications in the injection loader design or its operating conditions to prevent particle segregation at NSWC.

A homogeneous distribution of particles is often critical to the performance of extruded munitions and propellant grains. MRI can also be used to examine the homogeneity of extruded PEP products. At the NSWC program planning meeting, LMMS agreed to image grains or ropes extruded by NSWC. This activity will commence when specimens are received from NSWC.

One technical goal of the SERDP processing program is to develop thermoplastic elastomers (TPEs) as advanced, recoverable binders for cleaner PEP production. In order to study TPE processing we will need to add heat control to our flow mockup device for future TPE studies. Higher temperature processing studies of TPEs has been proposed to begin in the second year of this program. We plan to explore the use of non-energetic TPE suspensions in injection loading and twin-screw extruder processes. Appropriate rheological measurements will be performed to determine the flow characteristics of TPEs and TPE suspensions, which are expected to be highly non-Newtonian and therefore have different shear-induced particle migration behavior compared to that of suspensions with Newtonian suspending fluids. In conjunction with NAWC, LANL, and Sandia, we will first examine TPE-based model suspensions in simple viscometric flows to assess the fundamental migration characteristics using MRI and rheometry. These studies

will be followed by MRI investigations of the same materials in injection loading and twin-screw extrusion. The data can be used to guide the development of theoretical and simulation studies of processing TPE-based propellants at MIT and CIT. Optimal processing of TPE-based PEPs should result in minimal scrap during production. Both manufacturing scrap and the final product, at the end of its useful life, can ultimately be recovered for future reuse to minimize the overall life-cycle pollution and to achieve SERDP's goal.